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THERMAL ANALYSIS CHARACTERIZATION OF ELASTOMERS AND CARBON BLACK FILLED RUBBER COMPOSITES FOR ARMY APPLICATIONS

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ABSTRACT

A number of elastomeric based materials used in Army tank track pads have been analyzed by a variety of thermal analysis techniques which include thermogravimetric analysis, differential scanning calorimetry, thermomechanical analysis, and dynamic mechanical analysis. These measurements have been developed to yield data concerning the chemical composition of the complex elastomer system, the cure chemistry and conversion of the rubber, the glass transition temperature(s) of the elastomers, the tensile storage modulus as a function of temperature, and the use of thermogravimetric analysis as a quality control procedure for track pads.

Keywords: tracked vehicles.

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NOMENCLATURE

AMC-HQ - Army Materiel Command - Headquarters
BFG - BF Goodrich
BR - Butadiene Rubber
C - Cured
EXP - Experimental
FR - Firestone Tire & Rubber Co.
G4 - Goodyear Tire Co.
GS - Ground Side
MRL - Materials Research Laboratories - Australia
NAT - Natural Rubber
NR - Natural Rubber
PB - Polybutadience
PBD - Polybutadiene Rubber
PHR - Parts per hundred rubber
QPL - Qualified Products List
RW - Roadwheel Side
SP - Standard Products
SBR - Styrene-Butadiene Rubber
SR - Synthetic Rubber (SBR or SBR-BR)
TR - Track Rubber
U - Uncured

INTRODUCTION

Thermal analytical techniques have been shown by many workers to provide important information pertaining to the analysis of rubber used in applications ranging from automotive and aircraft tires to rubber belts, hoses, and seals. Although thermal studies on rubber materials closely parallel the advances of rubber technology that have occurred over the past 150 years, the use of modern thermal analytical techniques, such as shown in Table 1, enables the analytical chemist to rapidly and accurately perform a variety of procedures to assist the rubber chemist with compositional analysis, elastomer identification, and determining the state of cure of the rubber compound. A detailed list of information that can be obtained by the use of modern thermal analytical techniques is shown in Table 2. Reviews by Sircar,[1] Brazier,[2] and Maurer[3] are illustrative of the versatility and importance of thermal analytical techniques.

Rubber end items are as important to the U.S. Army as they are in the commercial sector. The U.S. Army annually spends tens of millions of dollars for the purchase of rubber tires and other component parts of cars, trucks, and tracked vehicles. Current annual repair and replacement costs for track rubber used in tanks and other track vehicles are estimated to be in the range of $100,000,000; this estimate is expected to double within the next ten years with the full implementation of the M-1 main battle tank into the Army inventory.* Rubber components in fuel handling equipment, aircraft, howitzers, and missiles also play an important role in the proper operation of these systems. The Army Materials and Mechanics Research Center (AMMRC) and the Army Materiel Command (AMC) recognize both the near- and long-term need for a viable elastomer R&D effort to ensure that the Army's requirements for satisfactory rubber products are achieved.†

Although thermal analysis is widely used for analysis of rubber items in commercial applications, there are few reports or other documentation of the use of modern thermal analytical techniques for analysis of rubber items used by the Army. This report describes our work to develop a thermal analysis program on the carbon black filled rubber compounds of interest to the Army with an emphasis on track rubber end items. Preliminary reports on this work were presented at the 1983 DARCOM Rubber Review‡ and to TACOM, May 1984.**

EXPERIMENTAL

Materials

The materials used in this study were either laboratory compounds provided by Ft. Belvoir or Red River Army Depot (RRAD), known samples from commercial sources,

*U.S. Army Tank-Automotive Command, Track and Suspension R&D Symposium, 29-30 March 1982.

†AMC Elastomer Research and Development Program - FY85, Army Materials and Mechanics Research Center, December 1984.

‡DARCOM Elastomer Review, Ft. Belvoir, VA, 8-9 November 1983.

**SINGLER, R. E. AMMRC Rubber Characterization and Testing - Status Report, TACOM Track Effort Group Meeting, 25 April 1984.

1. SIRCAR, A. K. *Characterization of Elastomers by Thermal Analysis.* Journal of Scientific and Industrial Research, v. 41, 1982, p. 536.

2. BRAZIER, D. W. *Applications of Thermal Analytical Procedures in the Study of Elastomers and Elastomer Systems.* Journal of Rubber Chemistry and Technology, v. 53, 1980, p. 437.

3. MAURIER, J. J. *Thermal Characterization of Polymeric Materials.* Chapter 6, E. A. Turi, ed., Academic Press, NY, 1981.

or production samples provided by the Tank-Automotive Command (TACOM) or RRAD. The production samples were purchased by the Army under contract to private industry. Complete lists of samples are given in Table 3. Most samples are prefixed with "TR," which stands for "track rubber." In cases where the sample is a rubber compound of known composition, formulation is provided in Table 4 or in the appendix. The production compounds are of undisclosed composition.

Analytical Procedures

Thermogravimetric analysis (TGA), differential thermogravimetric analysis (DTG), and differential scanning calorimetry (DSC) were performed on all samples given in Table 3. Other methods studied included dynamic mechanical analysis (DMA) and thermomechanical analysis (TMA).

TGA-DTG were run using both the DuPont 1090 and 990 analyzers coupled with the 951 TGA module. The scans were measured by heating a 5-mg to 15-mg sample from ambient temperature to 550°C in a flow of nitrogen (flow rate of approximately 75 cc/min) and a heating rate of 10°C/min (1090) or 20°C/min (990) and then heating at the same rate to 850°C in a flow of air (flow rate of approximately 75 cc/min).

DSC scans were measured with a DuPont 910 Differential Scanning Calorimeter Cell. The DSC curves were produced by heating each sample from -110°C to 500°C at a heating rate of 10°C/min in a flow of nitrogen.

Thermomechanical analysis scans were measured on a Perkin-Elmer TMS-1, utilizing the penetration probe. Each sample was heated from -120°C to 50°C at a heating rate of 5°C/min.

Dynamic mechanical measurements were made utilizing a Rheometrics Dynamic Spectrometer on samples which were approximately 63 mm long, 11 mm wide, and 5 mm thick. Each sample was heated from -160°C to 110°C in a constant flow of nitrogen.

RESULTS

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis yields a considerable amount of information concerning the chemical composition of the elastomer system. The controlled heating process in nitrogen and air closely parallel the traditional wet chemical analysis procedures given in ASTM D297,[4] except that TGA is more rapid and could be employed as a quality control procedure for production rubber compounds. In fact, ASTM task group E37O1.09 has recently received approval for its document on the "Standard Practice for Compositional Analysis by Thermogravimetry;" a method designed basically for compounded rubber materials.*

*LARKIN, D. F. Detroit Diesel Allison, February 1985, Private Communication.

4. *Method for Rubber Products - Chemical Analysis.* 1983 Annual Book of ASTM Standards, ASTM D297-81, v. 09.01.

TGA can be utilized very specifically and accurately to determine the concentration of total organic components, carbon black, and ash in vulcanized and uncured materials. A representative TGA-DTG curve for an SBR vulcanizate is shown in Figure 1. The measurement can differentiate between the highly volatile matter [moisture, plasticizer, residual solvents, oils, or other low boiling (300°C or less)] components and medium volatile matter (including the rubber type). After the organic and polymeric components have been pyrolyzed, a plateau region is obtained (around 550°C); changing over to an air atmosphere oxidizes the carbon black, leaving the ash residue. The method is intended for use in problem solving, quality control, and material screening where a compositional analysis is desired or a comparison can be made with a known material of the same type. In addition, the derivative phase of the TGA plot can be used for identification of the rubber and, also, in some cases, quantification of polymer blends containing NR and synthetic rubbers.

Figure 2 shows the comparative TGA-DTG scans for new and acetone extracted samples taken from the ground side of a T-156 track block sample (TR-27). For the unextracted sample (top), the TGA trace shows a broad shoulder in the temperature range 229°C to 422°C; this is also followed by a slow rise in the DTG trace in the same temperature region. In contrast, for the extracted sample (bottom), there is no slow weight loss below 400°C; rather, there is a sharp drop commencing around 415°C. The DTG trace does not start to rise above the base line until approximately 400°C. The peak maximum for the extracted and unextracted samples are both measured at approximately 500°C.

The data obtained on the TR systems have been tabulated in Tables 5 through 9. A number of comments can be made concerning these data:

1. For comparison of known formulations (TR's 38-44, 93-96, 111-116) versus TGA measured parameter, the % organics and the % carbon black are very consistent in almost every case. The % residue or % inorganics vary in a number of samples. It is assumed here that the residue is the original inorganic components of the rubber compound; however, workers have shown that in some cases small corrections must be made for nonvolatile residues from the organic components.[2] The muffle furnace results (Table 9) are much closer to the theoretical values. This is to be expected, for a much larger sample is used when ashing in a muffle furnace, and any inhomogenities in the track rubber samples can be nearly completely eliminated.

2. For general purpose rubber (SBR-BR-NR) compounds, the DTG or derivative curve can be utilized to determine the type of elastomer system in each of the materials.[1] Natural rubber exhibits a peak maximum at approximately 365°C while SBR-BR and BR exhibit a peak at approximately 450°C. No differentiation can be made between SBR and BR. Quantification of NR versus SBR and/or BR can be obtained from DTG curves, however.

Examples of three different systems are given in Figure 3 for SBR-BR (top), SBR-BR-NR (middle), and NR (bottom). Note, in the top trace (TR-90), a peak maximum between 450°C to 500°C, which is characteristic for SBR-BR. No differentiation can be made between SBR and BR. A peak maximum at 400°C is observed, in the middle trace (TR-89), in which 35 wt % of the rubber content is NR. The bottom trace (TR-86) is a foreign track rubber compound of unknown composition; however, the DTG shows that this is most likely a 100% NR compound.

Although this report has utilized DTG analysis only for qualitative analysis of the elastomer system, quantitative analysis most likely could be obtained by comparison with a series of samples of known elastomer content. This would enable the analyst to determine the limits of detection of NR in the presence of SBR-BR and vice versa.

3. Table 6 illustrates the data obtained for uncured and cured track rubber samples. The data show that very little change occurs in the % organics, % carbon black, and % residue after curing of the elastomer system. One might expect the weight loss to be lower at 300°C and 400°C for a cured specimen. However, the results tabulated in Table 6 do not show any consistency of lower weight loss for cured specimens. In addition to the 50% weight loss, the temperature does not indicate substantial difference in uncured versus cured materials.

Differential Scanning Calorimetry (DSC)

The state or extent of cure of an elastomer is very important in determining the quality and useful life of a track rubber system. Thermogravimetric analysis has been shown to be an excellent tool for compositional analysis of rubbers but this technique has one very serious shortcoming. The results on uncured versus cured elastomer analysis do not show any significant difference between identical formulations.

A DSC analysis is required in order to determine if an elastomer system is cured efficiently and to determine the extent of cure. Figures 4 and 5 are DSC scans of an uncured and cured rubber system. The uncured rubbers exhibit a broad exotherm in the region of 150°C to 220°C for the uncured system and the absence of this exotherm for the cured specimens. This exothermic peak is caused by the reaction of the sulfur-accelerator system resulting in the crosslinking network of the cured elastomer system. The extent of cure can be determined by measuring the ΔH of the uncured material and comparing this result to the ΔH of the cured system. Cure exotherm temperatures and ΔH values are tabulated in Table 10 for selected TR samples. Theoretically, if a system is totally cured and no other exothermic chemical reactions are occurring, then $\Delta H=0$. In some cases, such as TR-40, TR-44, TR-90, TR-93, TR-95, TR-111, and TR-113, $\Delta H=0$; therefore, the elastomer is totally cured.

Thermomechanical Analysis (TMA) and Dynamic Mechanical Analysis (DMA)

Thermomechanical analysis and dynamic mechanical analysis are excellent techniques for determining the glass transition temperature (T_g) of rubbers. Tables 11 and 12 show the T_g data obtained by TMA and DMA. Table 13 illustrates the known T_g's of natural rubber, cis-polybutadiene rubber, and styrene-butadiene-1500 rubber in the uncured and cured state.[1] The data illustrates that the tabulated T_g of every sample can be matched to either NR, cis-BR, or SBR-1500.

Diblend and triblend compositions can cause a problem with identification by T_g analysis. As shown by the data in Table 12, the following can be stated:

1. Uncured diblends of SBR and BR exhibit two distinct transitions using DMA (TR-111, 60 SBR, T_g = -48°C and 40 BR, T_g = -98°C) but only show one T_g (-57°C) by TMA.

2. Cured diblends of SBR and BR exhibit one transition using DMA (TR-112, 60 SBR, 40 BR), T_g = -59°C and TMA, T_g = -59°C.

3. Uncured triblends of SBR, BR, and NR exhibit two distinct transitions using DMA (TR-113, 30 SBR, 30 BR, 30 NR, T_g = -98°C for BR and T_g = -49°C for SBR and NR) but only show one T_g (-64°C) by TMA.

4. Cured triblends of SBR, BR, and NR exhibit one transition using DMA (TR-114, 35 SBR, 30 BR, 30 NR), T_g = -59°C and TMA, T_g = -59°C.

Sircar and Lamond[5] showed that diblends of SBR/BR exhibit a T_g intermediate between those of SBR and BR which varies with sample composition (Figure 6). This phenomena is also shown with the TR sample T_g data.

Analysis of Unknown Compounds

One example of an unknown track rubber material, TR-21, is taken to illustrate the methodology utilized to determine its chemical composition. TGA shows approximately 61% organic material, 6% of which would be considered additives, extractable or highly volatile material (moisture, plasticizer, residual solvent, light oils, or other low boiling components), 36% carbon black, and 2.5% residue or ash content. The DTG curve indicates a peak at 450°C using the 1090 system with a slight shoulder at 410°C and the 990 data using twice the heating rate yielded a peak at 500°C. By comparison with the DTG traces in Figure 3, TR-21 is most likely a synthetic rubber (SBR or SBR-BR) compound with no NR component. In addition, the DSC analysis did not show an exotherm in the 150°C to 200°C region, indicating that the vulcanization process was essentially complete.

The glass transition measurement becomes very significant in determining the rubber system. The T_g measured -42°C by DSC and -43°C by TMA, therefore, the rubber material is only the SBR type.

U.S. Versus Foreign Track Rubber

Whereas specification MIL-T-11891D required all U. S. track rubber to be synthetic (except for bushings), no such restriction necessarily applied to foreign track. The Tank-Automotive Command (TACOM) continually evaluates foreign track to determine if any of these materials or designs would be applicable to U.S. Army vehicles. Our TGA studies have shown some differences between U.S. and foreign track rubber. Table 14 identifies various unknown materials, based on the DTG analysis from Table 5. One can see, for instance, that the German Leopard Tank Track has used NR compounds for over 10 years (TR-86 and TR-92). Similarly, the British employ NR compounds in the

5. SIRCAR, A. K., and LAMOND, T. G. *Identification of Elastomers in Tire Sections by Total Thermal Analysis. I. Tread and Black Sidewall.* Journal of Rubber Chemistry and Technology, v. 48, 1975, p. 301.

track pads as well. Since some of these countries report satisfactory track rubber performance, the revised U.S. specification, MIL-T-11891D, which allows for the use of NR or any materials in the track, may be a step in the right direction toward improving U.S. track rubber performance.

CONCLUSION

From the procedures described in this manuscript, one can obtain a considerable amount of information on the chemical composition and level of cure of the total elastomer system. This does not preclude the use of other analytical procedures and techniques for a more complete analysis and evaluation of these complex track rubber materials.

ACKNOWLEDGMENT

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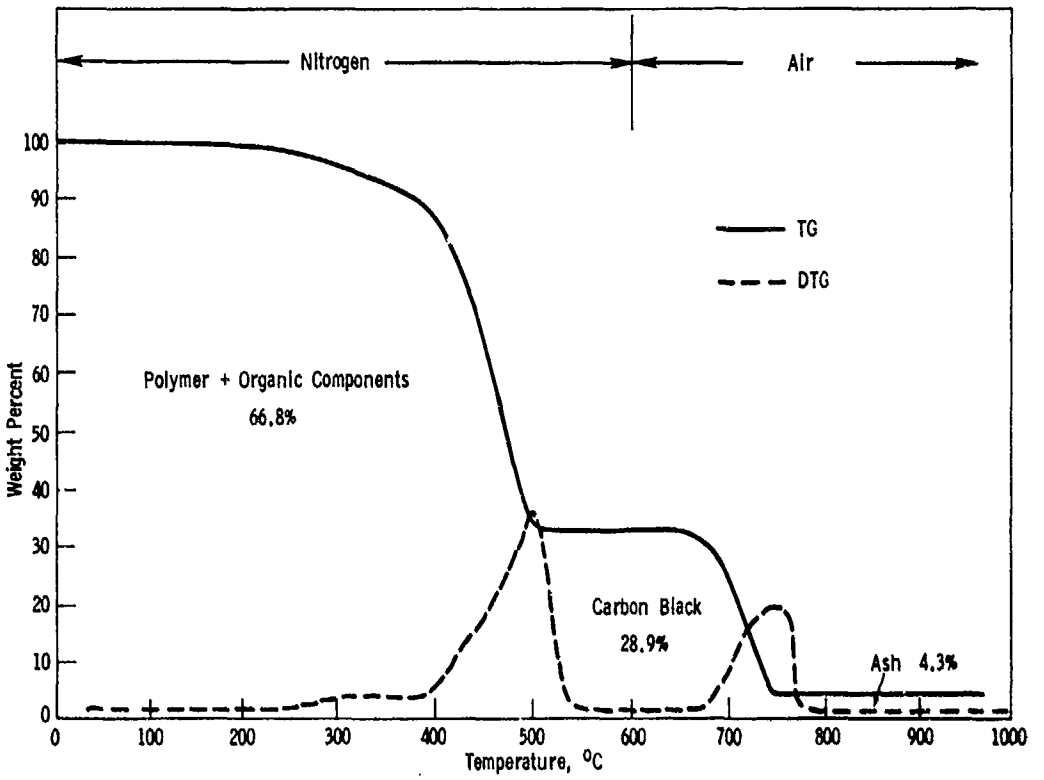

Figure 1. Thermogravimetric analysis of a styrene-butadiene (SBR) rubber vulcanizate showing weight losses for organic, carbon black and inorganic components.

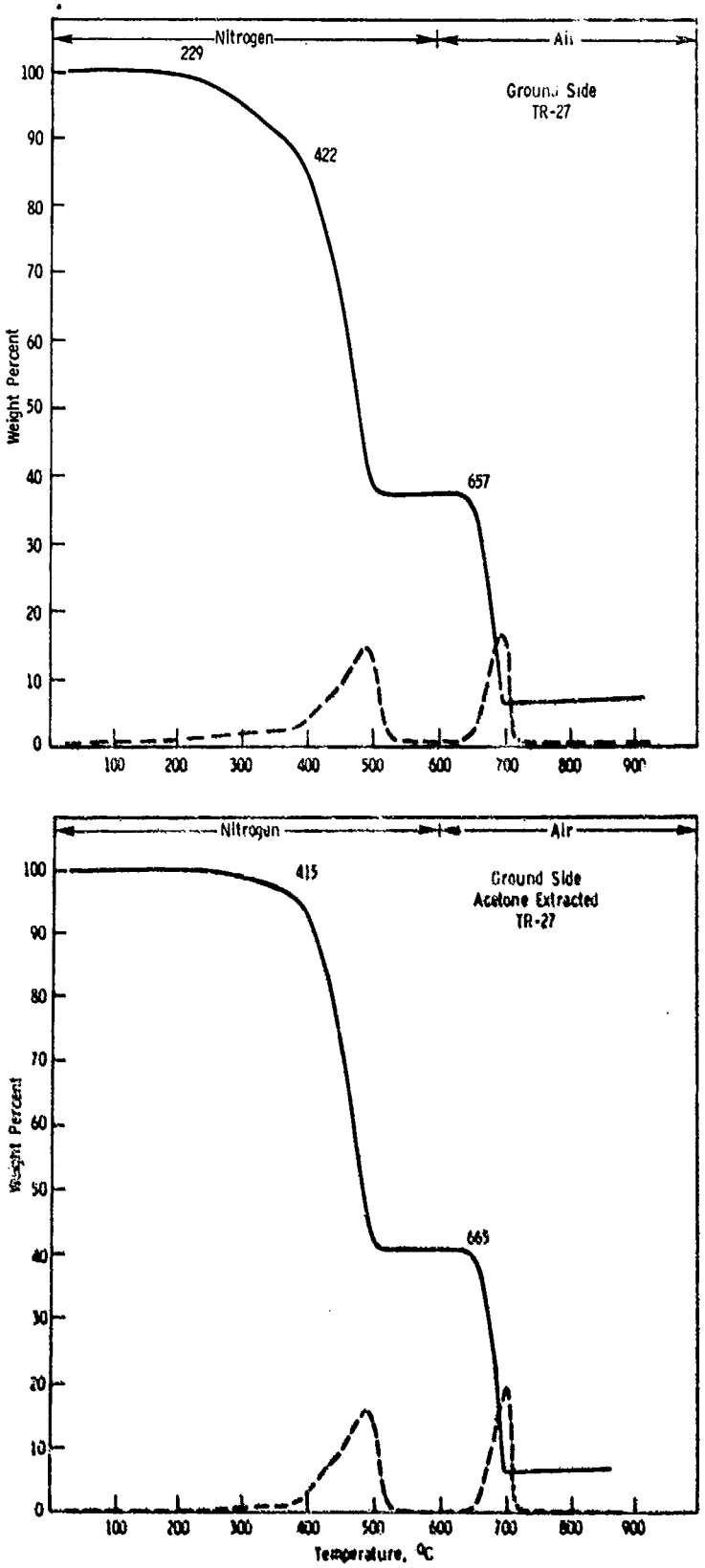

Figure 2. Thermogravimetric analysis (TGA-DTG).

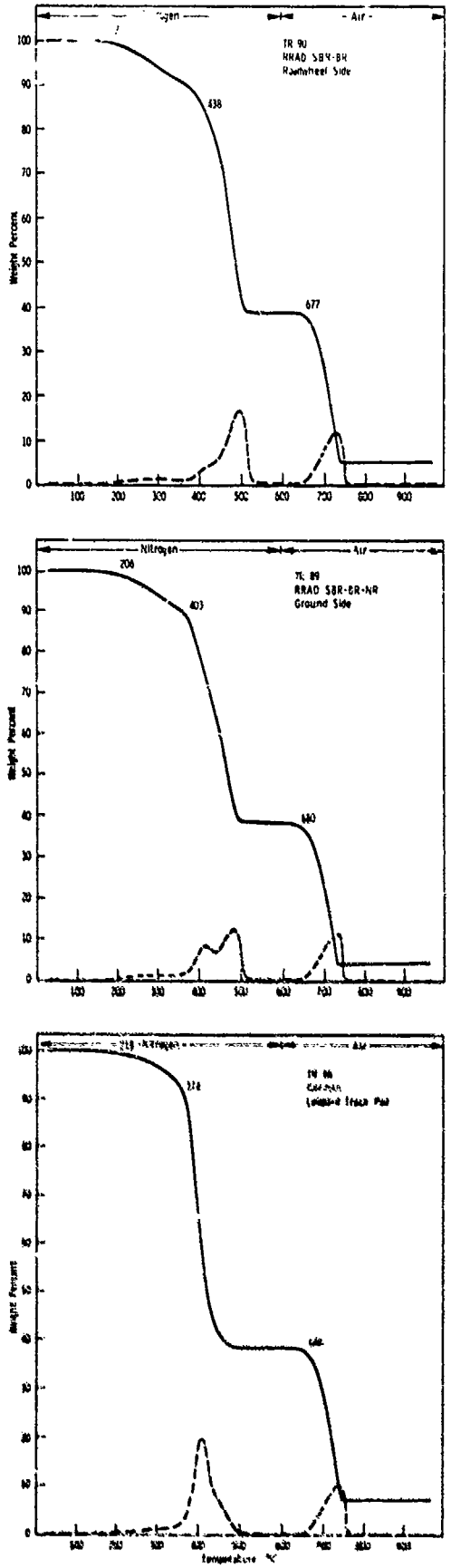

Figure 3. Thermogravimetric analysis (TGA-DTG) track rubber.

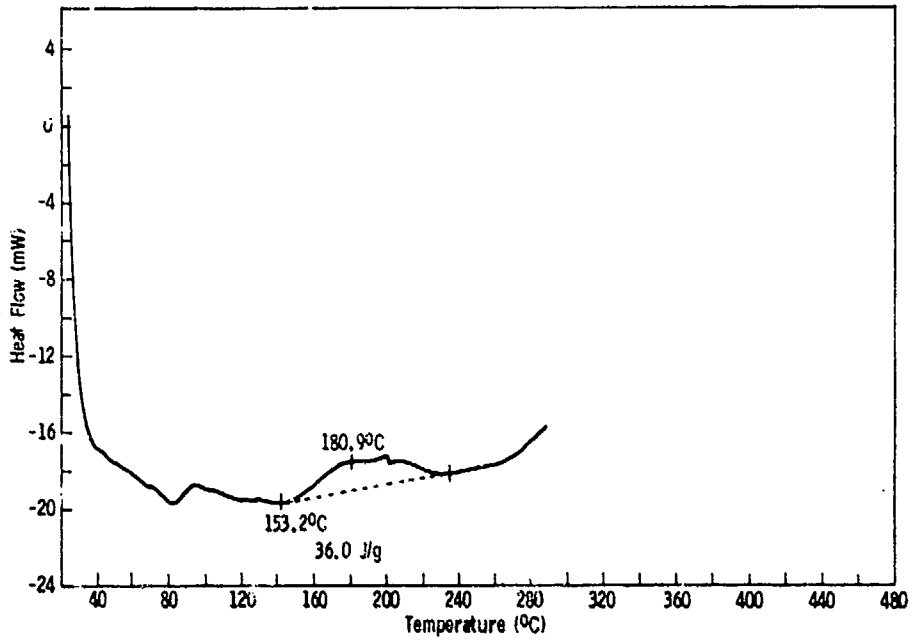

Figure 4. DSC of uncured SBR vulcanizate.

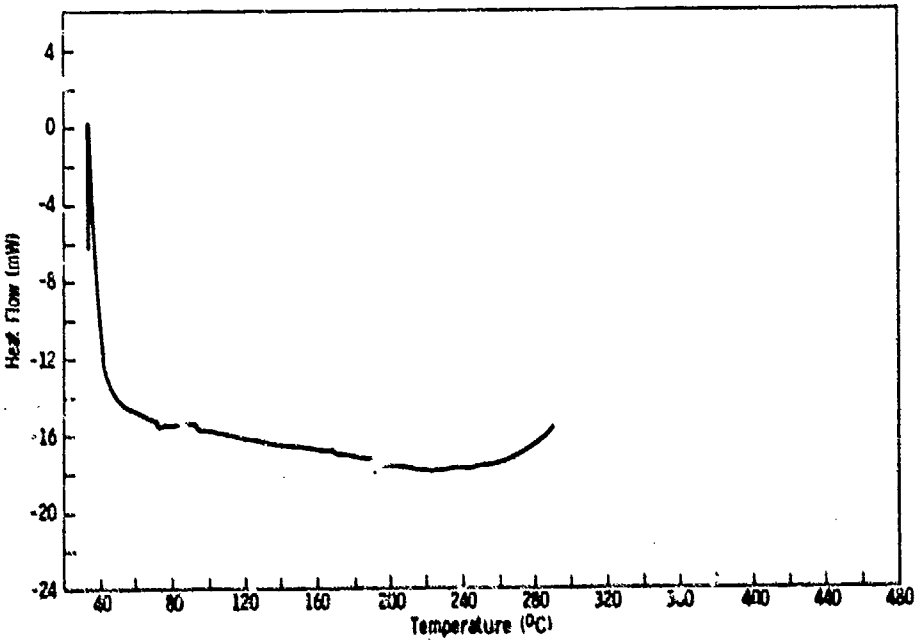

Figure 5. DSC of cured SBR vulcanizate.

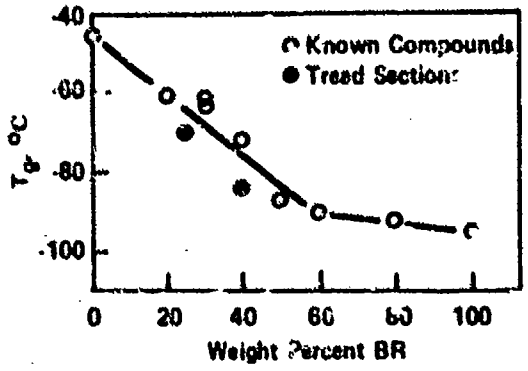

Figure 6. T_g of SBR/BR versus weight percent BR.

Table 1. COMMON THERMOANALYSIS TECHNIQUES[1]

Abbreviation	Technique	Response Measured
DTA	Differential Thermal Analysis	Temperature Difference
DSC	Differential Scanning Calorimetry	Energy (Heat) Difference
TGA	Thermogravimetry	Weight Change
DTG	Differential Thermogravimetry	Rate of Weight Change
TMA	Thermomechanical Analysis	Dimensional Changes
DTMA	Differential Thermomechanical Analysis	Rate of Change of Dimensions

Table 2. CHARACTERIZATION OF ELASTOMERS BY THERMAL ANALYSIS

DSC Measure Changes in Heat Flow	TGA and DTG Measure Weight Changes	Measure Dimensional Changes
Thermal Capacity	% Volatile, Water, Solvent	Thermal Expansion
Melting Point, T_g	% Plasticizer, Oil, Extender	Softening Point
% Crystallinity	% Polymer	Heat Deflection Temperature
Curing Profile	% Carbon Black	Modulus, Creep
Blend, Copolymer Analysis	% Carbonate	Mold Shrinkage
Additive Analysis	Degradation Profile	
Thermal Degradation	Thermal Stability	
Oxidative Degradation	Oxidation Stability	
Elastomer Identification	Elastomer Identification	
	Plasticizer Identification	

Table 3. TRACK RUBBER SAMPLES

TR Number	Origin	Composition*
15	BFG 100-JB-15	uncured NR
16	BFG 100-JB-15	cured NR
17	BFG 146-JB-1	uncured SBR-BR
18	BFG 146-JB-1	cured SBR-BR
19	BFG 100-JB-16	uncured WR-NR
20	BFG 100-JB-16	cured WR-NR
21	FR NB-907-QPL	MIL-T-11891B - Unk
22	FR TS-730-SR	Exp - Unk
23	FR TS-740-NR	Exp - Unk
24	FR NJ-417-QPL-RW	MIL-T-11891B - Unk
25	SP Control	MIL-T-11891B - Unk
26	SP NR	Exp - Unk
27	GY T-156 GS New	MIL-T-11891B - Unk
27	GY T-156 RW New	MIL-T-11891B - Unk
38	Ft. Belvoir	15-SBR-2B - Uncured & cured
39	Ft. Belvoir	15-SBR-17A - Uncured & cured
40	Ft. Belvoir	15-SBR-25 - Uncured & cured
41	Ft. Belvoir	15-NAT-2B - Uncured & cured
42	Ft. Belvoir	15-NAT-11B - Uncured & cured
43	Ft. Belvoir	15-NAT-18C - Uncured & cured
44	Ft. Belvoir	15-NAT-22 - Uncured & cured
72	Ft. Belvoir	15-PBD-1 - Uncured & cured
73	Ft. Belvoir	15-PBD-2 - Uncured & cured
74	Ft. Belvoir	15-PBD-3 - Uncured & cured
75	Ft. Belvoir	15-TP-B - Cured & uncured unk
76	Ft. Belvoir	15-TP-B-1 - cured & uncured
84	GY T-156 GS	MIL-T-11891B - Unk
85	GY T-156 RW	MIL-T-11891B - Unk
86	TACOM	German Leopard - 7/72 Unk
87	RRAD	L-67-TB - cured
88	RRAD	L-68-TB - cured
89	RRAD	L-67-TB uncured
90	RRAD	L-68-TB - uncured
92	MRL	Leopard I - 3/76 Unk
93	RRAD	Table 4 - Ref 14A - uncured
94	RRAD	Table 4 - Ref 14A - cured
95	RRAD	Table 4 - Ref 14A - uncured
96	RRAD	Table 4 - Ref 10L - cured
98	Ft. Belvoir	15-NSP-2A - uncured
99	Ft. Belvoir	15-NSP-2A - cured
100	AMMRC-OC	Table 4 - Ref 14A
101	Ft. Belvoir	15-TP-E - Unk
111	Ft. Belvoir	Table 4 - 15-TP-10LX - uncured
112	Ft. Belvoir	Table 4 - 15-TP-10LX - cured
113	Ft. Belvoir	Table 4 - 15-TP-14AX - uncured
114	Ft. Belvoir	Table 4 - 15-TP-14AX - cured
115	RRAD	Table 4 - Ref 10L - cured
116	RRAD	Table 4 - Ref 14A - cured
117	RRAD	P29 - uncured - unk
118	RRAD	P29 - cured - unk
120	AMMRC-OC	Table 4 - SPAL-32 - Triblend
124	RRAD	SP QPL - Bushing Cmpd - unk
127	TACOM	British Chieftain-AVON - unk
128	TACOM	Swedish Skega - unk
129	TACOM	British Vickers - unk
130	TACOM	French AMX 13 - unk
131	AMC HQ	Japan - unk
132	TACOM	French AMX 30 - unk
133	TACOM	Austrian Kuerassier - unk

*Exp-unk = experimental unknown composition purchased under mil specifications. 10L and 10LX are different batches of the same composition; 14A and 14AX as well as Table 4. Known compositions are given either in Table 4 or the appendix.

Table 4. MIL-T-11891D TRACK BLOCKS AND PADS RUBBER COMPOUNDS

Materials	Parts Per Hundred Rubber-PHR	
	Ground Side	Wheel Side
Styrene-Butadiene SBR-1500	35	60
Polybutadiene Taktene-220	30	40
Natural Rubber SMR-20	35	0
N220 Carbon Black	65	65
Zinc Oxide	3	3
Stearic Acid	1.50	1.50
Sunolite 100 - Hydrocarbon Wax	1.50	1.50
Santoflex 13 - Antidegradant	3	3
Flectol Flakes - Antidegradant	2	2
Sundex 790 - High Aromatic Oil	4	4
Sulfur	1.3	1.3
Dibs Sulfenamide Accelerator	3.2	3.2
Santogard PVI	0.2	0.2
	184.70	184.70

Table 5. COMPOSITIONAL ANALYSIS BY THERMOGRAVIMETRY

TR Number	1090 Data		990 Data	
	TGA	DTG Peak, °C	TGA	DTG Peak, °C
15	% Organics, 65.31 % Carbon Black, 31.76 % Residue, 2.82	405	% Organics, 66.13 % Carbon Black, 30.22 % Residue, 3.64	420
16	% Organics, 65.91 % Carbon Black, 30.72 % Residue, 3.53	395	% Organics, 63.45 % Carbon Black, 32.53 % Residue, 4.02	422
17	% Organics, 62.07 % Carbon Black, 35.36 % Residue, 2.62	435(S) 400(SH)	% Organics, 60.11 % Carbon Black, 35.99 % Residue, 3.57	500
18	% Organics, 61.95 % Carbon Black, 35.64 % Residue, 2.45	442(S) 410(SH)	% Organics, 61.05 % Carbon Black, 35.38 % Residue, 3.90	500
19	% Organics, 65.40 % Carbon Black, 30.67 % Residue, 5.20	395(S) 345(SH)	% Organics 63.84 % Carbon Black, 29.72 % Residue, 6.44	425
20	% Organics, 64.52 % Carbon Black, 31.34 % Residue, 4.57	400	% Organics, 64.61 % Carbon Black, 29.84 % Residue, 5.55	425
21	% Organics, 61.77 % Carbon Black, 36.15 % Residue, 2.09	450(S) 410(SH)	% Organics, 60.40 % Carbon Black, 36.40 % Residue, 3.20	500
22	% Organics, 64.99 % Carbon Black, 31.26 % Residue, 3.81	450(S) 375(M)	% Organics, 62.97 % Carbon Black, 32.04 % Residue, 4.99	495(S) 425(M)
23	% Organics, 63.31 % Carbon Black, 34.67 % Residue, 1.89	375(S) 440(M)	% Organics, 62.27 % Carbon Black, 34.73 % Residue, 2.99	430(S) 485(M)
24	% Organics, 62.00 % Carbon Black, 35.12 % Residue, 2.87	470	% Organics, 59.60 % Carbon Black, 38.00 % Residue, 2.40	502(S) 340(W)
25			% Organics, 60.71 % Carbon Black, 35.71 % Residue, 3.75	500
26			% Organics, 63.20 % Carbon Black, 31.70 % Residue, 5.30	430
27 - CS	% Organics, 64.71 % Carbon Black, 32.79 % Residue, 2.55	450	% Organics, 63.45 % Carbon Black, 32.53 % Residue, 4.02	494(M) 325(W)
27 - RW	% Organics, 58.44 % Carbon Black, 38.82 % Residue, 2.51	450	% Organics, 58.63 % Carbon Black, 39.36 % Residue, 2.81	490
38 - UC				
38 - C	% Organics, 67.52 % Carbon Black, 29,49 % Residue, 2.99	450(S) 390(SH)	% Organics, 67.87 % Carbon Black, 29.32 % Residue, 2.81	493(S) 290(W)
39 - UC	% Organics, 67.89 % Carbon Black, 30.14 % Residue, 2.00	450		

Table 5 (Continued)

TR Number	1090 Data		990 Data	
	TGA	DTG Peak, °C	TGA	DTG Peak, °C
39 - C	% Organics, 67.97		% Organics, 67.47	
	% Carbon Black, 30.92	460(S)	% Carbon Black, 29.72	500
	% Residue, 1.18	410(SH)	% Residue, 2.81	
40 - UC	% Organics, 69.28		% Organics, 68.00	
	% Carbon Black, 28.55	465(S)	% Carbon Black, 28.00	493
	% Residue, 2.20	375(SH)	% Residue, 4.00	
40 - C	% Organics, 68.60		% Organics, 66.40	
	% Carbon Black, 28.41	455	% Carbon Black, 30.40	497
	% Residue, 2.69		% Residue, 2.40	
41 - UC	% Organics, 68.00		% Organics, 66.97	
	% Carbon Black, 27.93	380	% Carbon Black, 28.90	413*
	% Residue, 3.17		% Residue, 4.13	
41 - C	% Organics, 68.05			
	% Carbon Black, 28.62	385		
	% Residue, 3.90			
42 - UC	% Organics, 67.69		% Organics, 65.00	
	% Carbon Black, 30.00	380(S)	% Carbon Black, 30.83	405*
	% Residue, 2.37	440(SH)	% Residue, 4.17	
42 - C	% Organics, 67.52			
	% Carbon Black, 30.09	380		
	% Residue, 2.45			
43 - UC	% Organics, 67.56		% Organics, 66.67	
	% Carbon Black, 29.73	375(S)	% Carbon Black, 28.84	406*
	% Residue, 2.78	425(SH)	% Residue, 4.50	
43 - C	% Organics, 68.41		% Organics, 68.0	
	% Carbon Black, 29.28	375(S)	% Carbon Black, 29.4	405*
	% Residue, 2.33	425(SH)	% Residue, 2.6	
44 - UC	% Organics, 67.81			
	% Carbon Black, 29.30	380(S)		
	% Residue, 2.96	425(SH)		
44 - C	% Organics, 64.92		% Organics, 62.30	
	% Carbon Black, 31.42	395(S)	% Carbon Black, 34.02	420
	% Residue, 3.66	440(SH)	% Residue, 3.69	
73 - C	% Organics, 67.33	470(S)	% Organics, 66.40	
	% Carbon Black, 30.63	375(W)	% Carbon Black, 29.60	508(S)
	% Residue, 2.05	435(SH)	% Residue, 4.00	420(SH)
74 - UC	% Organics, 67.10	480(S)		
	% Carbon Black, 30.05	370(W)		
	% Residue, 2.93	445(SH)		
74 - C	% Organics, 67.75	460(S)	% Organics, 64.40	
	% Carbon Black, 30.35	370(W)	% Carbon Black, 31.60	495
	% Residue, 1.88	445(SH)	% Residue, 4.00	
75 - C	% Organics, 63.42		% Organics, 64.40	
	% Carbon Black, 33.12	475(S)	% Carbon Black, 31.60	495(S)
	% Residue, 3.49	440(SH)	% Residue, 4.00	330(W)
76 - UC	% Organics, 62.38			
	% Carbon Black, 35.93	450(S)		
	% Residue, 1.73	400(W)		
76 - C	% Organics, 62.39			
	% Carbon Black, 35.66	455(S)		
	% Residue, 1.99	400(SH)		
84	% Organics, 64.43		% Organics, 61.70	
	% Carbon Black, 32.40	450(S)	% Carbon Black, 32.00	507
	% Residue, 3.22	420(SH)	% Residue, 6.40	

Table 5 (Continued)

TR Number	1090 Data TGA	1090 Data DTG Peak, °C	990 Data TGA	990 Data DTG Peak, °C
85	% Organics, 58.77		% Organics, 58.80	
	% Carbon Black, 38.44	465(S)	% Carbon Black, 38.00	495(S)
	% Residue, 2.89	415(SH)	% Residue, 2.60	350(W)
86	% Organics, 62.24		% Organics, 61.45	
	% Carbon Black, 31.63	370(S)	% Carbon Black, 32.53	413*
	% Residue, 6.17	420(SH)	% Residue, 6.02	
87	% Organics, 63.46		% Organics, 62.3	485(S)
	% Carbon Black, 34.53	470(S)	% Carbon Black, 34.2	410(M)
	% Residue, 1.66	375(M)	% Residue, 3.5	300(W)
88	% Organics, 61.91	470(S)	% Organics, 61.56	
	% Carbon Black, 34.86	425(W)	% Carbon Black, 34.04	497(S)
	% Residue, 3.25	375(SH)	% Residue, 4.41	305(W)
89	% Organics, 63.07		% Organics, 61.30	
	% Carbon Black, 35.18	470(M)	% Carbon Black, 34.98	485(S)
	% Residue, 1.76	400(M)	% Residue, 3.72	417(M)
90	% Organics, 62.47	470(S)	% Organics, 61.35	
	% Carbon Black, 34.38	380(W)	% Carbon Black, 33.54	495(S)
	% Residue, 3.16	425(SH)	% Residue, 5.11	300(W)
91	% Organics, 96.06	440(S)		
	% Carbon Black, 3.76	295(M)		
	% Residue, 0.16	375(W)		
92	% Organics, 63.26		% Organics, 62.76	
	% Carbon Black, 34.63	382	% Carbon Black, 33.09	413
	% Residue, 1.99		% Residue, 4.15	
93	% Organics, 61.95	475(S)	% Organics, 61.34	480(S)
	% Carbon Black, 36.30	420(M)	% Carbon Black, 34.82	407(M)
	% Residue, 1.79	400(W)	% Residue, 3.84	280(W)
		393(SH)		
94	% Organics, 61.76		% Organics, 62.0	
	% Carbon Black, 36.62	470(S)	% Carbon Black, 35.60	485(S)
	% Residue, 1.73	395(M)	% Residue, 2.40	395(M)
95	% Organics, 61.83		% Organics, 62.25	
	% Carbon Black, 35.87	475(S)	% Carbon Black, 34.14	495(S)
	% Residue, 2.36	440(SH)	% Residue, 3.61	300(W)
96	% Organics, 62.15		% Organics, 62.00	
	% Carbon Black, 35.33	475(S)	% Carbon Black, 34.80	485(S)
	% Residue, 2.16	440(SH)	% Residue, 3.20	295(W)
98	% Organics, 63.97		% Organics, 64.00	
	% Carbon Black, 34.48	385(S)	% Carbon Black, 33.60	420(S)
	% Residue, 1.62	450(M)	% Residue, 2.40	470(SH)
99	% Organics, 63.62		% Organics, 64.80	
	% Carbon Black, 35.04	385(S)	% Carbon Black, 34.00	420(S)
	% Residue, 1.38	450(M)	% Residue, 1.20	470(SH)
100	% Organics, 60.61		% Organics, 60.24	493(S)
	% Carbon Black, 37.03	480(S)	% Carbon Black, 36.02	420(M)
	% Residue, 2.43	390(M)	% Residue, 3.74	305(W)
101	% Organics, 69.11		% Organics, 68.11	
	% Carbon Black, 28.97	460(S)	% Carbon Black, 27.69	493(S)
	% Residue, 1.96	420(SH)	% Residue, 4.20	345(W)
111	% Organics, 62.80		% Organics, 62.80	
	% Carbon Black, 36.27	470(S)	% Carbon Black, 35.60	505
	% Residue, 0.963	435(SH)	% Residue, 1.60	
112	% Organics, 61.80	475(S)	% Organics, 62.65	
	% Carbon Black, 36.18	425(W)	% Carbon Black, 35.74	505
	% Residue, 1.69	375(SH)	% Residue, 2.01	

Table 5 (Continued)

TR Number	1090 Data		990 Data	
	TGA	DTG Peak, °C	TGA	DTG Peak, °C
113	% Organics, 61.10		% Organics, 62.14	
	% Carbon Black, 37.45	465(S)	% Carbon Black, 37.86	500(S)
	% Residue, 1.47	395(M)	% Residue, 1.94	430(M)
114	% Organics, 61.69		% Organics, 61.60	
	% Carbon Black, 36.77	465(S)	% Carbon Black, 36.80	500(S)
	% Residue, 1.54	395(M)	% Residue, 1.60	430(M)
115	% Organics, 62.86		% Organics, 62.00	
	% Carbon Black, 36.04	475(S)	% Carbon Black, 34.80	503(S)
	% Residue, 1.09	440(SH)	% Residue, 3.20	325(W)
116	% Organics, 61.73		% Organics, 62.40	495(S)
	% Carbon Black, 36.54	475(S)	% Carbon Black, 35.60	420(M)
	% Residue, 1.71	380(M)	% Residue, 2.00	315(W)
117	% Organics, 60.85		% Organics, 59.71	
	% Carbon Black, 35.99	460(S)	% Carbon Black, 36.91	495(S)
	% Residue, 3.19	400(W)	% Residue, 3.20	440(SH)
118	% Organics, 61.16		% Organics, 60.03	
	% Carbon Black, 36.47	450(S)	% Carbon Black, 36.19	500(S)
	% Residue, 2.43	390(W)	% Residue, 3.82	450(SH)
120	% Organics, 58.36			
	% Carbon Black, 40.13	435(S)		
	% Residue, 1.74	450(M)		
124	% Organics, 74.40		% Organics, 74.40	
	% Carbon Black, 21.99	370(S)	% Carbon Black, 22.40	427(s)
	% Residue, 3.61	470(w)	% Residue, 3.20	520(w)
127	% Organics, 63.63/63.69		% Organics, 62.65	
	% Carbon Black, 32.93/32.85	395(S)	% Carbon Black, 33.33	417(S)
	% Residue, 3.49/3.50	490(M)	% Residue, 4.02	460(SH)
128	% Organics, 61.97			
	% Carbon Black, 36.20	455(S)		
	% Residue, 1.54			
129	% Organics, 60.096		% Organics, 58.00	395(S)*
	% Carbon Black, 36.34	390(S)	% Carbon Black, 39.20	430(M)
	% Residue, 3.58	435(SH)	% Residue, 2.80	270(W)
130	% Organics, 62.32			
	% Carbon Black, 35.34	380(S)		
	% Residue, 2.40	455(M)		
131	% Organics, 68.46			
	% Carbon Black, 28.08	380(S)		
	% Residue, 3.51			
132	% Organics, 63.48			
	% Carbon Black, 33.32	390(S)		
	% Residue, 3.13	455(M)		
133	% Organics, 63.15			
	% Carbon Black, 33.35	390		
	% Residue, 3.57			

*990 Data - 10°C/min, all others, 20°C/min

NOTE: S = strong, M = medium, W = weak, and SH = shoulder

Table 6. CURED VERSUS UNCURED TRACK RUBBERS

TR Number	Description	% Organics		% Carbon Black		% Residue		% Weight Loss 300°C		% Weight Loss 400°C		50% Weight Loss, °C	
		uncured	cured	uncured	cured	uncured	cured	uncured	cured	uncured	cured	uncured	cured
15 and 16	100-JB-15, NR	65.31	65.91	31.76	30.72	2.82	3.53	6	3	37	44	405	401
17 and 18	146-JB-1,SBR-BR	62.07	61.95	35.34	35.64	2.62	2.45	11	12	27	27	448	452
19 and 20	100-JB-16, WR	65.60	64.52	30.67	31.34	5.20	4.57	3	2	43	42	408	408
38	15-SBR-2B	67.52		29.49		2.99		4		14		470	
39	15-SBR-17A		67.97		30.92		1.18		5		16		463
40	15-SBR-25	69.28	68.60	28.55	28.41	2.20	2.69	6	5	16	15	460	460
41	15-NAT-2B	68.00	68.05	27.93	28.62	3.17	3.90	7	5	42	47	410	405
42	15-NAT-11B	67.69	67.52	30.00	30.09	2.37	2.45	6	7	48	43	400	420
43	15-NAT-18C	67.56	68.41	29.73	29.29	2.78	2.33	7	6	53	50	398	400
44	15-NAT-22	67.81	66.23	29.30	30.05	2.96	3.66	7	5	51	47	400	400
76	15TP-B-1	62.38	62.39	35.92	35.66	1.73	1.99	9	8	24	22	455	467
87 and 89	L-67-TB	63.07	63.45	35.18	34.53	1.76	1.66	6	6	23	23	432	460
88 and 90	L-68-TB	62.47	61.91	34.38	34.86	3.16	3.25	4	6	13	15	475	475
93 and 94	14A Ground side	61.95	61.76	36.30	36.62	1.79	1.73	5	6	21	18	458	433
95 and 96	10L Wheel side	61.83	62.15	35.87	35.33	2.36	2.16	5	6	14	15	475	475
98 and 99	Control Cmpd	63.97	63.62	34.48	35.04	1.62	1.38	5	5	32	30	420	424
111 and 112	15TP-10LX	62.80	61.80	36.27	36.18	0.96	1.69	6	5	16	14	433	431
113 and 114	15TP-14AX	61.10	61.69	37.45	36.77	1.47	1.54	7	6	23	23	426	432
117 and 118	P29	60.85	61.16	35.99	36.47	3.19	2.43	7	7	12	23	470	455

Table 7. THERMOGRAVIMETRIC ANALYSIS DATA

TR Number	Highly Volatile Material 200°C	300°C	Weight Loss at 400°C, %	50% Weight Loss, °C
15	1	6	37	405
16	1	3	44	401
17	3	11	27	448
18	3	12	27	452
19	1	3	43	408
20	1	2	42	408
21	1	6	16	467
22	3	7	23	455
23	2	7	34	440
27	1	5	10	490
38-U*	0	4	14	470
38-C*	3	5	18	450
39-U	0	9	20	465
39-C	1	5	16	463
40-U	3	6	16	460
40-C	3	5	15	460
41-U	2	7	42	410
41-C	0	5	47	405
42-U	2	6	48	400
42-C	3	7	43	420
43-U	3	7	53	398
43-C	2	5	53	405
44-U	3	7	51	400
44-C	2	5	47	400
73-C	1	4	9	479
74-C	1	3	8	485
75-C	1	5	9	478
76-U	3	9	24	455
76-C	2	8	22	467
84	3	6	17	465
85	2	6	13	475
86	3	7	53	400
87	2	6	23	460
88	2	6	15	475
89	2	6	23	432
90	1	4	13	475
91	0	7	42	410
92	3	6	64	380
93	0	5	21	458
94	1	6	18	433
95	1	5	14	475
96	2	6	15	475
98	1	5	32	420
99	1	5	30	424
100	0	3	20	475
101	1	6	17	430
111	1	6	16	433
112	1	5	14	431
113	1	7	23	426
114	1	6	23	432
115	1	6	14	475
116	1	6	23	430
117	4	7	17	470
118	3	7	23	455
120	2	8	13	431
124	3	6	53	480
127	0	4	25	445
128	2	6	14	475
129	2	9	32	440
130	2	5	31	445
131	3	6	50	400
132	2	4	27	451
133	1	3	38	445

*U = uncured, C = cured

Table 8. MIL SPEC 11891D TRACK RUBBERS

TR, Type and Number	% Organics		% Carbon Black		% Residue	
	Theoretical	Measured	Theoretical	Measured	Theoretical	Measured
10L-U-95*	63.2	61.8	35.2	35.9	1.62	2.36
10L-C-96*	63.2	62.2	35.2	35.3	1.62	2.16
10L-U-111	63.2	62.8	35.2	36.3	1.62	0.96
10L-C-112	63.2	61.8	35.2	36.2	1.62	1.69
10L-C-115	63.2	62.9	35.2	36.0	1.62	1.09
14A-U-93	63.2	62.0	35.2	36.3	1.62	1.79
14A-C-94	63.2	61.8	35.2	36.6	1.62	1.73
14A-U-113	63.2	61.1	35.2	37.5	1.62	1.47
14A-C-114	63.2	61.7	35.2	36.8	1.62	1.54
14A-C-116	63.2	61.7	35.2	36.0	1.62	1.71

*U = uncured, C = cured

Table 9. COMPARISON OF ASH OR RESIDUE CONCENTRATION

TR Number	Type	Muffle Furnace	TGA 1090	TGA 990
38	15-SBR-2B, uncured	2.88	2.99	2.81
38	15-SBR-2B, cured	2.87	2.89	
39	15-SBR-17A, uncured	2.83	3.36	
39	15-SBR-17A, cured	2.79	2.60	2.81
40	15-SBR-25, uncured	3.14	2.20	4.00
40	15-SBR-25, cured	3.09	2.69	2.40
41	15-NAT-2B, uncured	2.89	3.17	4.13
41	15-NAT-2B, cured	2.89	3.90	
42	15-NAT-11B, uncured	2.88	2.37	4.17
42	15-NAT-11B, cured	2.83	2.65	
43	15-NAT-18C, uncured	3.24	2.78	4.50
43	15-NAT-18C, cured	3.16	2.33	
44	15-NAT-22, uncured	3.73	2.96	
44	15-NAT-22, cured	3.20	3.66	3.69

Table 10. DIFFERENTIAL SCANNING CALORIMETRY OF CURED AND UNCURED TRACK RUBBERS

TR Number	H, J/g		Cure Exotherm Temperature, °C	Other Thermal Events, °C
	Uncured	Cured		
15 and 16	31.5	13.2	195	Uncured, Endotherm at 167
19 and 20	11.5		175	
38	20.2	0.1	171	
39	21.1	8.1	171	
40	1.0	0	170	Uncured, endotherm at 145
42	18.0	6.3	188	Uncured, endotherm at 140
43	18.2	6.1	197	Uncured, endotherm at 140 (s), 150 (w), 155 (w)
44	16.8	0	143	
73	4.42	2.54	182	Uncured, endotherm at 145
74	4.08	0	180	Uncured and cured, endotherm at 200
88 and 90	7.90	0	190	
93 and 94	5.29	0	191	
95 and 96	5.21	0	195	
98 and 99	8.48	0.81	170	
111 and 112	4.30	0	200	
113 and 114	6.33	0	193	
117 and 118	12.3	1.84	192	

Table 11. GLASS TRANSITION TEMPERATURES DETERMINED BY PENETRATION TMA

TR Number	Type of Rubber	T_g (°C)	TR Number	Type of Rubber	T_g (°C)
15	NR, Uncured	-57	44-U	NR	-60
16	NR, Cured	-57	44-C	NR	-59
17	SBR and PB, Uncured	-50	74-C	PB	-88.4
18	SBR and PB, Cured	-63	74-U	PB	-102.4
19	SBR and PB, Uncured	-60	75-C		-46.1
20	SBR and PB, Cured	-61.2	84		-48
21		-43	85		-49
22	SBR	-46	88		-65.3
23	NR	-57	89		-64.7
24		-43	90		-62.9
25		-38	92		-41.7
26		-57	93	Triolend	-105.2, -60.1
27-RW	SBR/BR	-66	94	Triblend	-62.4
27-GS	SBR	-50	95	SBR-PB	-54.1
38-U	SBR	-48	96	SBR-PB	-63.5
38-C	SBR	-46	98		-61.8
39-U	SBR	-48	99		-62.9
39-C	SBR	-45	100	Triblend	-65.9
40-U	SBR	-48	101		-51.2
41-U	NR	-59	111		-57.1
41-C	NR	-58	112	SBR-PB	-68.2
42-U	NR	-60	113	Triblend	-63.5
42-C	NR	-58	115	SBR-PB	-66.5
43-U	NR	-59	116	Triblend	-76.1
43-C	NR	-63	117		-54.1

Table 12. COMPARISON OF GLASS TRANSITION TEMPERATURES OF TRACK RUBBERS

TR Number	DSC, T°C	TMA, °C	Rheometrics, °C
16		-57	-60
18		-63	-63
21	-42	-43	
22	-43	-46	
23	-58	-57	
24	-45	-43	
25	-37	-38	
26	-54	-57	
27-GS	-49	-50	
27-RW		-66	
41 Cured	-57	-58	
75	-48	-46	
85	-42	-49	
93		-42	-101, -63
94		-58	-62
96		-64	-56
98	-58	-62	
99	-60	-63	
101	-55	-51	
111		-57	-98, -48
112		-59	-59
113		-64	-98, -49
114		-58	-59
115		-67	-60
116		-76	-110, -83, -61
117	-50	-54	
118	-48		-39

Table 13. GLASS TRANSITION TEMPERATURE OF SELECTED ELASTOMERS

Rubber Type	°C, Uncured	°C, Cured
Natural Rubber	-60	-56
Cis-Polybutadiene	-105	-95
SBR-1500	-49	-47

Table 14. UNITED STATES VERSUS FOREIGN TRACK RUBBER

TR	Country of Origin	DTG Peak, °C 1090 Data	Indentification
21	United States	410 (SH) 450 (S)	SR
24	United States	470	SR
27 - GS	United States	450	SBR
27 - RW	United States	450	SBR/BR*
84	United States	420 (SH) 450 (S)	SR
85	United States		SR
86	West Germany	370 (S) 420 (SH)	NR
92	Australia (West Germany)	382	NR
127	United Kingdom	395 (S) 450 (M)	NR/SR
128	Sweden	450 (S)	SR
129	United Kingdom	390 (S) 435 (SH)	NR/SR
130	France	380 (S) 455 (M)	NR/SR
131	Japan	380 (S)	NR
132	France	390 (S) 455 (M)	NR/SR
133	Austria	390	NR

SR = Synthetic rubber (SBR, BR or SBR/BR)

* For TR 27-GS, T_g = -50°C; TR 27-RW, T_g = -66°C. Values determined by TMA.

APPENDIX. COMPOSITIONS OF SAMPLES FROM TABLE 3

A. The following non-proprietary compounds were purchased from B.F. Goodrich

TR-15, 16	PHR	TR-17, 18	PHR
#3SS NR	100.0	1712 Oil extended SBR	68.75
Zinc oxide	5.0	CB 441 Oil extended BR	68.75
Stearic acid	1.0	Zinc oxide	5.00
N110 carbon black	55.0	Stearic acid	1.50
Pine tar softener	5.0	N234 carbon black	85.00
Antonize 67F (antiozonant)	2.0	Dutrex 916 Petroleum base softener	5.00
Age-Rite Resin D (antioxidant)	3.0	Antozite 67F	2.00
Goodrite 3146 (antioxidant)	1.0	Age-Rite Resin D	1.50
Santocure MOR (accelerator)	1.0	Santocure MOR	1.20
Sulfasan R	2.0	Sulfur	1.75
Sulfur	0.5	Recipe Wt. =	240.45
Recipe Wt. =	175.5	Specific Gravity =	1.17
Specific Gravity =	1.15		

TR - 17, 18 were wire reinforced versions of TR - 15, 16.

B. SBR Rubber Formulations - Ft. Belvoir

	PHR		
	TR-38	TR-39	TR-40
SBR Rubber, Firestone FRS-1500	100.0	100.0	100.0
Zinc oxide, Kadox 150	4.0	4.0	4.0
Stearic acid, #1 Rubber grade	2.0	2.0	2.0
SAF, N110 Black	45.0	45.0	45.0
Age-Rite Resin D, antioxidant	0.5	0.5	0.5
Antiozite 2-antiozonant	3.0	3.0	3.0
Sulfur, Rubber Makers	2.0	2.0	0.75
Santocure, accelerator	1.5	1.5	-
Butyl Tuads	-	-	0.625
Octoate Z	-	-	1.5
Acryl Lactate	-	-	1.0
Amax	-	-	1.875

C. Natural Rubber Formulations - Ft. Belvoir

	PHR			
	TR-41	TR-42	TR-43	TR-44
Natural Rubber, Smoked Sheet RSS-1	100.0	100.0	100.0	100.0
Zinc oxide - Hadox 150	4.0	4.0	4.0	4.0
Stearic acid, #1 Rubber grade	2.0	2.0	2.0	2.0
SAF Black, N110	45.0	45.0	45.0	45.0
Age-Rite Resin D, Antioxidant	0.5	0.5	0.5	0.5
Antiozite 2, Antiozonant	3.0	3.0	3.0	3.0
Sulfur, Rubber Makers	2.5	2.5	2.5	0.75
Santocure	0.8	0.8	0.8	-
Butyl Tuads	-	-	-	0.625
Octoate Z	-	-	-	1.5
Acryl Lactate	-	-	-	1.0
Amax	-	-	-	1.875

D. Polybutadiene Rubber Formulations - Ft. Belvoir

	PHR		
	TR-72	TR-73	TR-74
Polybutadiene	100.0	100.0	100.0
Zinc Oxide	4.0	4.0	4.0
Stearic acid	2.0	2.0	2.0
SAF Black, N110	45.0	45.0	45.0
Sulfur	2.0	2.0	2.0
Santocure	1.5	1.5	1.5

E. Miscellaneous Samples - Ft. Belvoir

	TR-76
	PHR
SBR	80.0
BR	20.0
Zinc oxide	4.0
Stearic Acid	1.0
Age-rite Resin D	2.0
Aminox	3.0
N339 Black	65.0
Sundex 790	20.0
Plasthall P-7092	5.0
Santocure NS	1.7
Sulfur	3.0

F. Miscellaneous Samples - Ft. Belvior

	PHR	
	TR-98	TR-99
NR	60.0	60.0
SBR	40.0	40.0
BR	30.0	30.0
Zinc oxide	3.0	3.0
Stearic acid	2.0	2.0
SAF Black N110	42.0	42.0
Age-rite Resin D	0.5	0.5
Antozite Z	5.0	5.0
Age-rite White	0.5	0.5
Piccopale 100	3.5	3.5
Sulfur	2.0	2.0
Santocure	1.5	1.5

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